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Environmental assessment of cod (*Gadus morhua*) from autoline fisheries

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Abstract

Purpose The main purpose of this study has been to document the environmental performance of products based on autoline-caught cod and the distribution of environmental impacts in the value chain from fishing to retail. Another aim has been to document the performed environmental improvement analyses.

Methods Standard life cycle assessment methodology has been employed and the following impact categories studied: global warming potential (GWP), acidification, eutrophication, photochemical oxidant formation, ozone layer depletion and cumulative energy demand.

Results and discussion Products derived from autoline-caught cod have a GWP in the range of 0.16–7.6/1.7–4.4 kg CO2-eq/kg product delivered to consumer, using economic and mass allocation, respectively. The main impacts come from fuel consumption and release of refrigerants in the fishery. The products studied represent each of the four major processing outputs. The differences between the products can partly be attributed to differences in methodology (system borders, allocation), partly to actual physical differences. A comparison with published results from other studies indicates that seafood products sourced from Northeast Arctic cod fished with the autoline method has a relatively good environmental performance. A number of possible options for improving the environmental performance of the products were identified. The most internal improvement action was stopping leakages in fish freezers.

Conclusions This study has given a detailed overview of the environmental performance of seafood products sourced from Northeast Arctic cod from autoline fisheries in Norwegian territorial waters. This study has demonstrated the usefulness of such results in improving the environmental performance of the products. However, the usefulness of the results in communication to external actors is limited because few data exists on other products fulfilling the same functions and using the exact same methodology and assumptions. In order to achieve comparability between results from competing products, it is necessary to use a standardised and detailed calculation method. At the moment, no such method seems to be available. The literature study indicated that the environmental impact of Northeast Arctic cod products sourced from autoline fisheries compares well with other cod products on the market. Some cod stocks are sustainably managed, others not. Hence, it is recommended to break down results not only to species level but also fish stock level when the aim is to guide seafood customers towards making informed purchasing decisions.

Keywords Autoline · Cod · Comparing environmental performance · Fish

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1 Background

Fish is a very important source of protein for the world's population. Annual production in 2006 was 81.9 million tonnes (FAO 2008). At the same time, many of the global fish stocks have been severely depleted According to the report from Food and Agriculture Organization, around 50% of the world's fisheries are fully exploited, only 25% are under or normally exploited. The production of farmed

fish is steadily increasing, from 40.4 million tonnes in 2002 to 51.7 million tonnes in 2006 while the output from capture fisheries fell slightly in the same period (from 93.2 to 92.0 million tonnes per year). The pressure on wild fish stocks has not been reduced (FAO 2008) partly because wild fish is an important part of farmed fish feed (Naylor et al. 2000; Naylor and Burke 2005; and Tacon 2005). Hence it is important to find ways of utilising the remaining wild fish in a more efficient way.

The effects of capture fisheries on biological system in the oceans are clearly important, but the effects of the industrial processes necessary for modern fisheries are also important, as summarised by Hospido and Tyedmers (2005). These include processes directly related to fishing such as the combustion of fuels in vessels but also the manufacture of equipment and boats. Even though the fishing phase dominates the impacts related to these processes (70–95% according to Hospido and Tyedmers (2005)), the remaining parts of the value chain is also important. Processing, storage, transports and not the least impacts related to the consumer is very important, as shown by Thrane (2006), Thrane et al. (2009) and Ziegler et al. (2003).

The total catch volume of Northeast Arctic cod was 460,000 tonnes in 2008, of which 70% was caught by trawl, the rest by gillnet, longline, Danish Seine and jigging (Gjøsæter et al. 2010). This cod stock is considered to be sustainably managed (Gjøsæter et al. 2010). The catch volume of coastal cod was 26,000 tonnes in 2009, mostly caught by passive gears such as gillnet, longline and jigging, but also by active gears such as trawl and Danish Seine (Gjøsæter et al. 2010). The coastal cod stocks are declining and considered not to be sustainably managed (Gjøsæter et al. 2010).

Thrane et al. (2009) has studied ecolabels for seafood products. Several ecolabels have been developed for seafood products, of which Marine Stewardship Council (MSC; http://www.msc.org/) has been the most commercially successful. This ecolabel does not address all environmental impacts connected with seafood products, but concentrates on some biological effects, primarily the effect on fish stocks. The Swedish ecolabel KRAV (www.krav.se), on the other hand, addresses not only these biological impacts but also other impacts. The labelling requirements include, e.g. a limit on fuel consumption per kilogram fish caught.

In this study, we evaluate the life cycle environmental impacts associated with products made from Northeast Arctic cod harvested in Norwegian partly automated longlining ("autoline") fisheries mainly in the Barents Sea and off Bear Island in the Svalbard Archipelago. The study is focused on products derived from the main processing fractions from one processing plant in western Norway. The products are followed until delivery to the customer.

2 Goal and scope

This study is a life cycle assessment of four different products made from cod caught with the autoline method in the Northeast Atlantic Ocean and the Barents Sea. The products represent the main fractions from cod processing. The life cycle from catch to final distribution has been included.

3 Aim and objective

The target of this study has been to:

- document the environmental performance of the products sourced from cod caught by the autoline fleet in Norwegian territorial waters;
- map the distribution of environmental impacts across the value chain from fishing to sale to the customer;
- demonstrate how the assessment was used to identify possibilities for reduction of environmental impact and quantify potential effect of such measures.

The motivation for the involved companies has been to achieve improvements in environmental performance. Another important motivation has been to provide consumers, buyers, retailers, restaurateurs, fishermen, processers, other actors in the seafood value chain as well as other interested parties with detailed information on the environmental impact of products from autoline-caught cod over the whole life cycle from catch to product on the market and compare with results from other studies.

4 Method

The study was carried out using life cycle assessment (LCA) methodology based on the ISO standards 14040 and 14044. The impact assessment method used for most impact categories was CML 2 baseline 2000, V2.04. For cumulative energy demand, the method used was CML 1992 V2.05 and Cumulative Energy Demand V1.05 by Ecoinvent. The following environmental impact categories are included in this study: global warming potential, acidification potential, eutrophication potential, photochemical ozone creation potential and cumulative primary energy demand.

The SimaPro 7.1.6 software was used together with the Ecoinvent 1.3/2.0 database in order to carry out the analyses performed.

4.1 Functional unit

The functional unit for the four products was:

1 kg wetpack, frozen, in 400 g packages, delivered to retailer in Sweden.
1 kg fish-burger, frozen, in 5 kg packages, delivered to institutional buyer (e.g. school) in Sweden.
1 kg processed cod loin product in 2 kg package, delivered to distribution centre in the UK.
1 kg processing residue, frozen, going to animal feed production in Norway.

4.2 Description of the system

The cod (*Gadus morhua*) used as raw material for these products are of the Northeast Arctic stock. It was caught in several parts of the Northeast Atlantic, usually the North Cape Bank, areas near Bear Island in the Svalbard archipelago and in the Bering Sea on 10 autoline vessels operated by the company Ervik Havfiske (Fig. 1).

The autoline-catching method is a variation of the traditional long-line fishing method where long lines with many baited hooks are left at sea for a time period of normally 6–12 h and then hauled aboard. The autoline method implies the use of automated equipment that sets and hauls the line, de-hooks the fish, unclips the hooks and stores the line and hooks. The fish is gutted relatively soon after being hauled, approximately 5–15 min. After gutting and head-cutting, the fish is sorted according to species and weight and frozen.

Cod, haddock, ling and tusk were target species in the autoline fisheries. All boarded catches were processed, landed and utilised. Discards are not allowed in Norwegian Territorial waters, but some fish is lost. The loss occurs when fish falls of the hooks during hauling and the crew do not manage to retrieve them. A proportion of this fish is damaged and will not survive (Huse 2003). Bycatch of non-fish species happens, but very rarely. The most common non-fish bycatch is seabirds. On the fishing vessels, bird-scaring lines and other devices to minimise this bycatch are employed.

The frozen cod is processed ashore. After thawing, it is cut into loins (back part, the highest quality), belly and tail parts, block and mince (minced fish meat). The remaining parts such as skin, bones and other parts not suitable for human consumption are sold for use in animal feed. Some of the block and mince is mixed with other ingredients (e.g. wheat flour and vegetable fat) and deep fried. “Fishburger” is an example of such a product. Loins are mostly sold fresh, the rest of the products are packaged and sold frozen. Chilled loins are transported to customers abroad and used in a variety of products.

System boundaries The investigated system encompasses the fishing stage, processing, transport to wholesaler, storage, and transport to shop or professional user, except the processing residue (stops at arrival at the reprocessing plant) and loins product (stops at regional distribution centre). The production of inputs such as fuel and electricity were included in the analyses (Fig. 2).

The environmental impact of capital goods such as fishing vessels, processing plant, equipment and machines was not included in the system because of lack of accurate data. The impact of the construction of the fishing vessel has in some studies (Ellingsen and Pedersen 2004; Ziegler et al. 2003) been shown to be of importance, i.e. comprising more than 1% of one or more impacts, but in this study the impacts was estimated to be below 1% and hence not included.

Allocation Two main multiple output processes was included in the study: (a) fishery, yielding many different fish species; (b) processing, yielding many different products. The choice of allocation method in this case has been discussed in another article by Svanes et al. (2011); hence in this article, only a short presentation of the deliberations done is presented.

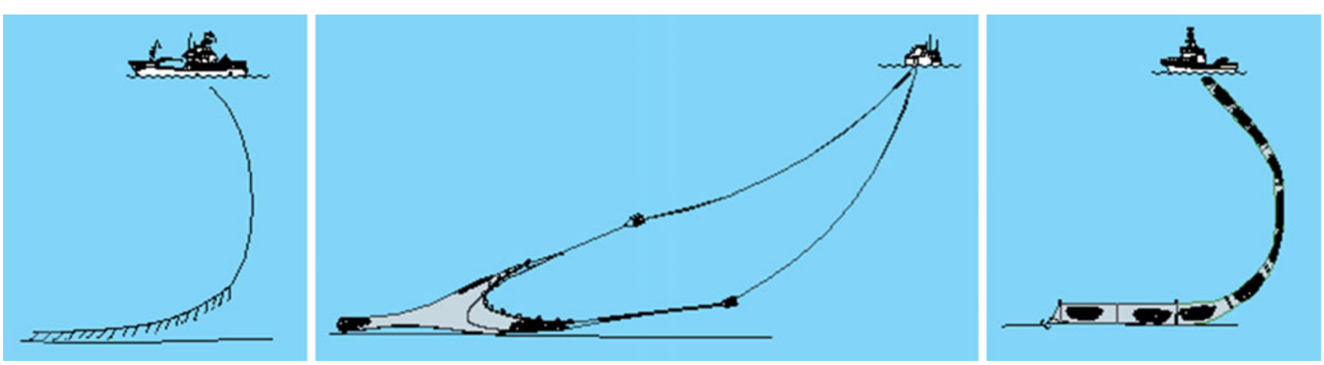

Fig. 1 Cod fishing methods (from *left* to *right*): Longlining, bottom trawl and gillnetting (source: Norwegian Directorate of Fisheries 2003)

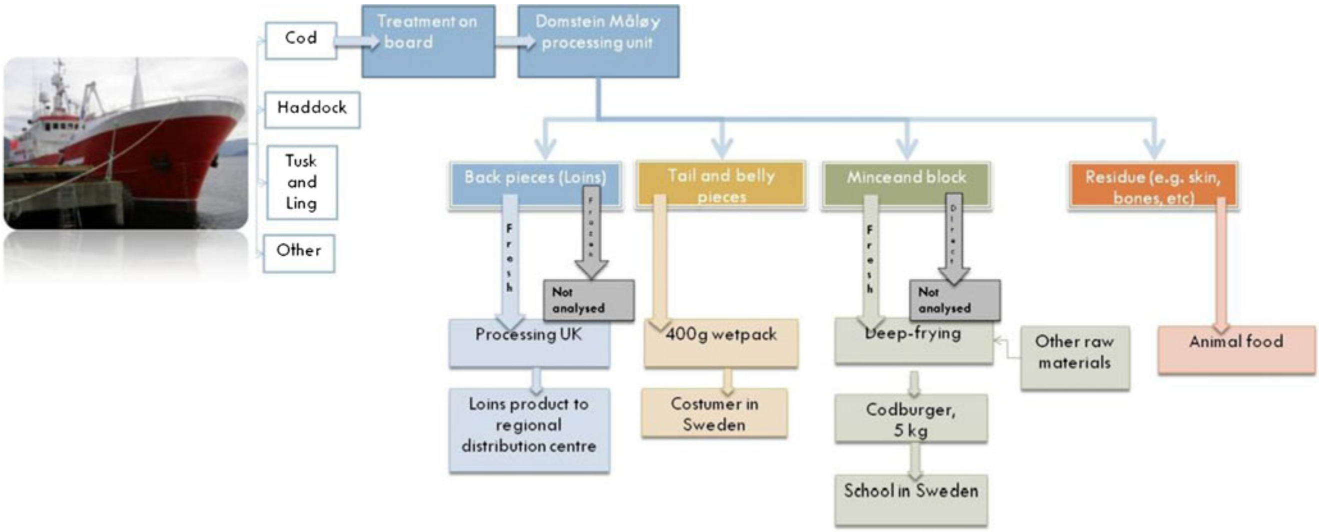

Fig. 2 Overview of the studied system

ISO 14044 recommends the following hierarchy for such cases.

1. Avoiding allocation by splitting processes.
2. Systems expansion
3. Allocation according to physical and biological causality.
4. Allocation using other principles.

Splitting of the processes was not possible for the fishing phase because the fish is caught in the same places with the same equipment. For the first part of the processing, the cutting, no splitting could be made but separate data for secondary processing into deep-fried products was obtained. Use of system expansion yielding a multi-functional FU was not chosen because an important aim of the study was to provide separate results on each product for the benefit of customers. System expansion using the avoided burden approach was not attempted due to lack of data (fisheries) and uncertainty regarding the choice of avoided products (processing). Allocation through the use of physical or biological causality was attempted but no such causality could be identified. Mass allocation and economic allocation are the most commonly used allocation methods in fish studies in recent years. Svanes et al. (2011) has studied the impacts of allocation methods on results and concluded that mass and economic allocation are the preferred methods taking into account the intended use of the data, but did not recommend one of these methods as preferable to the other. Hence in this study, it was decided to present results using both these allocation methods.

5 Life cycle inventory

Table 1 lists the inventory results. The list contains activity data and sources of data. The environmental impacts were calculated using the activity data and relevant Ecoinvent processes. Not all the inventory data was used in the LCA but presented here for the benefit of other research projects.

6 Results

This section contains results from the LCA study, a literature study and the environmental performance improvement analyses.

6.1 LCA results

The main results from the LCA of the four products at the beginning of the project are summarised in Table 2. The study was conducted in the period from 2007 until 2010. During that time, some improvements were made on a number of the older boats of the fishing fleet, resulting in large reductions in environmental impact, especially global warming potential (GWP). Table 3 shows the LCA results of the products at the end of the project period, after the mentioned improvements were carried out.

For most impact categories, the magnitude of the impact decrease in the order loin product > wetpack > cod burger > animal feed by-product. However, for eutrophication, the order is loin product > cod burger > wetpack > animal feed by-product.

The studied products have different system borders. The processing residue going to animal feed does not include reprocessing, repackaging and storage. The loins product, on the other hand, includes reprocessing and repackaging and longer transport distances than the other products. The loins were the only processing output being transported chilled, the others were frozen. This entailed a very different transport

Table 1 Inputs and outputs from autoline fisheries

Phase	Parameter	Source	Value
Fishery	Fuel consumption	Fishing company, using invoices and catch records	0.29 l Marine gas oil/kg caught whole fish
	Refrigerant loss	Maintenance company. Average for the fleet	0.33 g R22 per tonne fish
	Packaging	Usage: fishing vessel operator Manufacture: Ecoinvent database	0.7 g/kg fish. Laminated paper
	Bait	Amount: fishing vessel operator Squid: 150 l fuel/tonne	Average 0.068 g/kg whole fish (squid 0.038/mackerel 0.003/herring 0,017/saury 0.010)
		Saury: no data, assumed to be similar to squid	
		Herring and mackerel: assumed 0.2 l fuel/kg	
	Lost hooks and hook lines	Amount lost: fishing vessel operator Manufacture of hooks: manufacturer	0.97 g (steel), 0.65 g (polyester) per kg caught
		Manufacture of hook raw material: Ecoinvent	
		Manufacture of hook line: 0.1 kWh/1,000 lines. Electrical energy. Raw material: polyester	
		Manufacture of hook line raw material: Ecoinvent	
	Lost mainline	Amount and composition: equipment manufacturer	0.52 g PP, 0.78 g PS per kg fish caught
	Catch, 4 main species	Cod, haddock, tusk and ling	Cod: 35.66%, haddock 25.76%, ling 9.1% and tusk 16.43%
	Bycatch fish	Fishing vessel operator	11.5% of total catch
			Saithe, Greenland Halibut, Northern wolfish, Redfish
			Spotted catfish, Atlantic halibut, Blue ling, Wolfish
	Value of catch	Fishing vessel operator	Cod share of value: 41.3%
	Bycatch seabirds	Estimate from fishing company, based on reports from skippers	<0.3 birds per tonne caught fish
	Loss of fish	Estimate from fishing company, based on reports from skippers	<2% of total catch
	Effect on seabed	Not measured	Presumed to be negligible
	Ghostfishing	Not measured	Presumed to be negligible
	Consumption of anti-fouling agents	Average numbers for vessels, fishing vessel operator	0.03 g CuO/kg caught fish
	Consumption of chemicals	Manufacture: from Ecoinvent	All in litres/tonne caught fish
			Lubricating oil: 0.9 l
			Disinfectants: 0.01 l
			Cleaning agents: 0.24 l. (4% alcohol ethoxylate and 3% quarternary coco amine ethoxylate)
			Paint: 0.12 l
			Sealer coat: 0.09 l
			Rust remover: 0.012 l
			Thinner: 0.008 l

Table 1 (continued)

Phase	Parameter	Source	Value
	GWP of fishing vessel of 1904 GT and service lifetime 25 years	Calculated by Magerholm Fet et al. (2009)	1.94×10^{6} kg CO2-eqvivalents
Processing	Electricity demand	Thawing, cleaning, cutting, heating and freezers	0.36 kWh/kg
		Extra electricity demand for deep-fried products	0.21 kWh/kg
	Environmental impact from electricity production	The production mix for the NordEl area was used, i.e. percentage of electricity from each energy source like hydropower, coal, nuclear energy etc. For each energy source the environmental impact was calculated using Ecoinvent processes	
	Processing yield	Based on information from processor	Chilled loins 24%
			Frozen loins 3%
			Tail and belly parts: 21%.
			Block and mince: 12%
			Remaining part (skin, bone, ++): 40%.
	Prices	Prices are given as a fraction of the price of chilled loins.	Chilled loins 100%
			Frozen loins 78%
			Wetpack/IQF 62%
			Block and mince: 33%
			Animal feed: 1%
	Fish burger composition	Amount of non-fish ingredients: Processing company.	
		Data on production of ingredients: LCA Foods.	
Transport	Wetpack, IQF and burger to wholesale	Mode: truck. Distances: Transport company.	Distance processing to wholesale storage: 800 km
			Diesel consumption, average pr km: 0.42 l.
			Return load: 80%.
Wholesale	Energy demand	Energy demand: wholesaler	0.245 kWh/kg product
Transport to shop	Wetpack and IQF: Wholesale to shop.	Mode: truck	Distance wholesale - regional distribution centre: 485 km
		Distance: retail company	Distance regional distribution centre - shop: 100 km
Transport to shop	Fish burger to wholesale to user	Mode: truck	Distance wholesale - regional distribution centre:582 km
		Distance: sales company	Distance regional distribution centre - shop: 100 km
Energy use in shop	For wetpack	Carlson and Sonesson (2000)	1.0 kWh/kg

Table 2 Environmental impacts of cod products at the start of the project

		Loins product		Wetpack		Cod burger		Animal feed product	
		Economic	Mass	Economic	Mass	Economic	Mass	Economic	Mass
Global warming potential	kg CO_2-eq	10.1	5.2	5.1	3.0	2.4	2.3	0.2	2.4
Ozone layer depletion	kg CFC-11-eq	5.8E-05	2.0E-05	3.4E-05	1.8E-05	1.2E-05	1.2E-05	5.7E-07	1.8E-05
Photochemical oxidation	kg C_2H_4-eq	0.012	0.0057	0.0066	0.0087	0.0031	0.0030	0.0002	0.0033
Acidification	kg SO_2-eq	0.053	0.025	0.028	0.016	0.012	0.012	0.001	0.014
Eutrophication	Kg PO_4-eq	0.012	0.0058	0.0062	0.0085	0.0043	0.0043	0.0002	0.0031
Cumulative energy demand	MJ	112	68	58	39	27	27	2.7	24

solution, using large EPS boxes and ice. The cod burger is unique in that it contains a large proportion of non-fish ingredients, the others were sourced 100% from fish.

The ranking of the product according to their environmental impacts is the same using economic and mass allocation but the differences between the products are much higher using economic allocation. The effect on the result for the residue going to animal feed production is especially high, more than a factor of 10. The effect on the loins product and wetpack is also high, the result from economic allocation being 60–70% higher for economic allocation than for mass allocation.

The environmental impact of the construction of the fishing vessel was not included in this assessment. The effect of the construction was estimated to 21 g CO2-eq/kg fish caught based on the impact calculated by Magerholm Fet et al. (2009), average tonnage of the autoline vessels of 660 GT, a yearly catch of 1,300 tonnes of fish and an estimated life time of 25 years. This corresponds to 0.5% of the GWP of the loins and 0.9% of the wetpack product, both using mass allocation.

The distribution of the impacts in the value chain of the products, exemplified by global warming impact, is shown in Fig. 3. The fishery was identified to be the largest contributor except in the case of the animal feed product using economic allocation. In this case, the transport to the user had the highest impact. Figure 4 shows the distribution of GWP of different subsystems of the fishing phase. The fuel is used both for propelling the boats forward, operating equipment and powering onboard freezers. In this case, there was not sufficient data available to split the fuel consumption according to these purposes. The impact of fuel is 89% of total GWP, bait accounts for 5.3%, equipment 0.4% and other impacts (mainly refrigerant emissions) 5.6%. Lost equipment is hooks + feeder lines of which a few is lost on every trip and mainline which is lost or have to be replaced approximately every 2 years.

Figure 5 shows the distribution of cumulative energy demand (CED) in the value chain of the wetpack product (mass allocation). The combustion of fuel onboard the vessels is the dominant contributor to this impact, in the same way as with GWP. The other life cycle phases such as processing and retail account for a higher proportion of the total impact for CED than for GWP. The fuel consumption accounts for 45% of total CED but 60% of the total GWP. A similar pattern is observed for the other products. The energy used is either fuel or electricity.

Figure 6 shows the distribution of potential eutrophication impact across the value chain. The production of other ingredients gives the most important contribution. These ingredients are derived from agricultural products. One example is vegetable oil. The eutrophication impact of the fuel combustion is due to the release of NOx. The emissions of NOx was not monitored, but taken from Ecoinvent database data.

Table 3 Environmental impacts of cod products at the end of the project

		Loins product		Wetpack		Cod burger		Animal feed product	
		Economic	Mass	Economic	Mass	Economic	Mass	Economic	Mass
Global warming potential	kg CO_2-eq	7.6	4.4	3.6	2.2	1.8	1.8	0.16	1.7
Ozone layer depletion	kg CFC-11-eq	1.2E-05	5.0E-06	6.4E-06	3.3E-06	2.3E-06	2.2E-06	1.2E-07	3.3E-06
Photochemical oxidation	kg C_2H_4-eq	0.012	0.0057	0.0066	0.0037	0.0031	0.0030	0.0002	0.0033
Acidification	kg SO_2-eq	0.053	0.025	0.028	0.016	0.012	0.012	0.001	0.014
Eutrophication	Kg PO_4-eq	0.012	0.0058	0.0062	0.0085	0.0043	0.0043	0.0002	0.0031
Cumulative energy demand	MJ	112	68	58	39	27	27	2.7	24

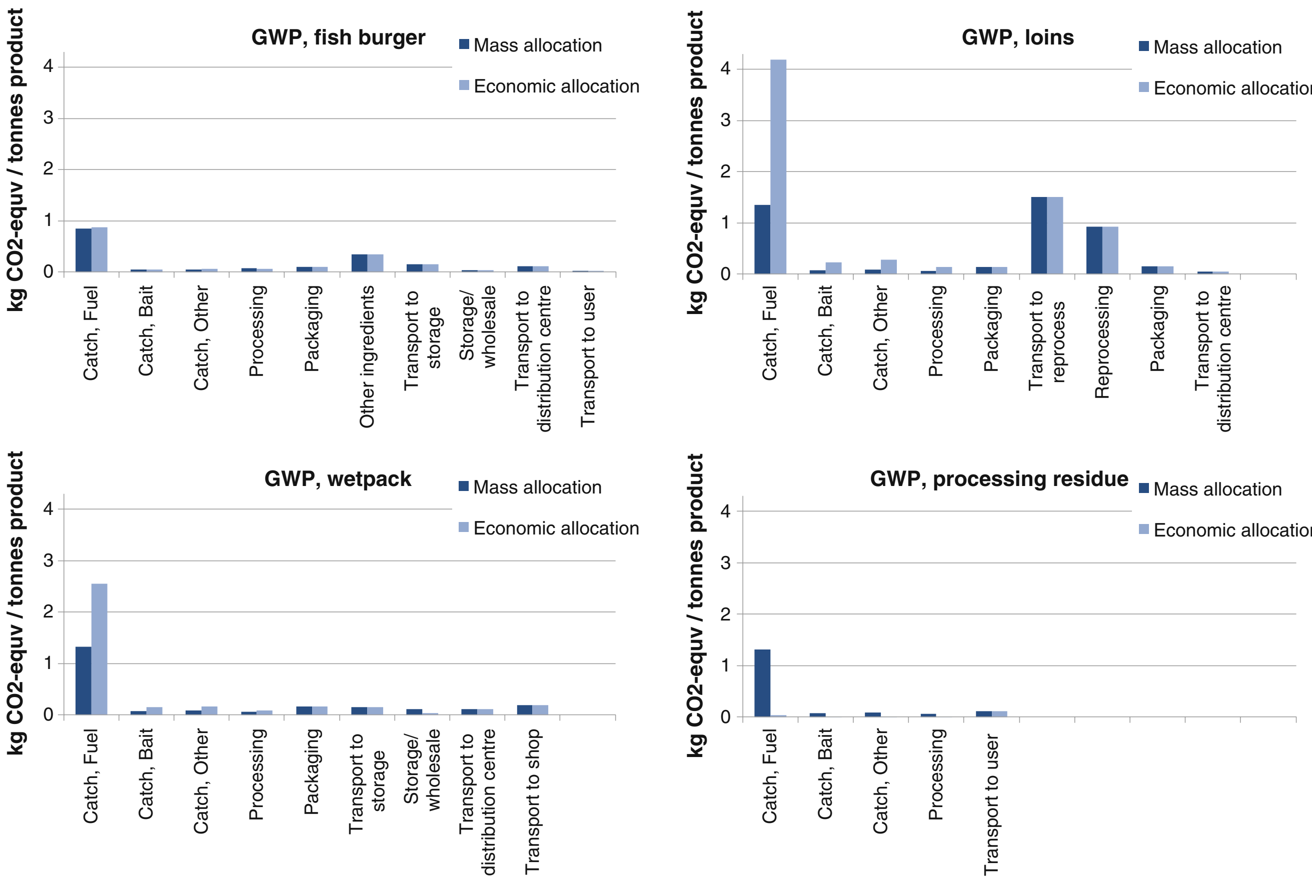

Fig. 3 Distribution of greenhouse gas emissions in the value chain of the four main products

The distribution of impacts across the value chain for the impact categories acidification potential, photochemical and oxidant potential are not shown here because they show a very similar pattern to the GWP.

6.2 Literature study

The environmental impact of seafood products based on cod has been reported in several studies. In this overview, only GWP results are mentioned as information on this impact is more abundant than on other impacts. One comparative study by Guttormsdóttir (2009) performed in Iceland reported a GWP of 1.58 kg CO2-eq/kg product for fillet from long-lined cod, whereas the corresponding number for the product from trawled cod was 5.14 kg CO2-eq/kg product. Ziegler et al. (2003) reported a GWP of 6.8/10 kg CO2-eq/kg product for fillets from gillnetted and trawled cod, respectively, using economic allocation. An Icelandic study (Jonsdottir 2008) of North Sea cod fillets from Icelandic factory trawlers gave a GWP of 4.5 kg CO2-eq/kg product, using mass allocation. A study of mixed Danish Fisheries (60% trawl, rest longlining, Danish Seine, purse seine) by Thrane (2003) gave GWP of 3.2 and 2.8 kg CO2-eq/kg ex-retail for frozen and fresh fillets, respectively. These numbers were based on a system expansion approach. Winther et al. (2009) reported a GWP of 3.7 kg CO2-eq/kg product for gutted cod and 2.3/2.4 kg CO2-eq/kg for fresh and frozen fillets, respectively, delivered to Paris. Mass allocation was used. The fish was caught with different fishing gears and techniques.

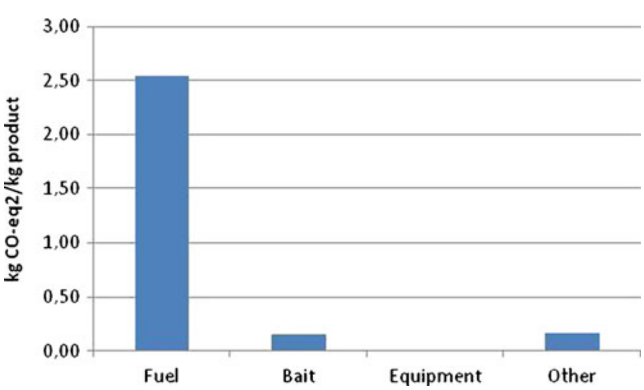

Fig. 4 Distribution of impacts during fishing, GWP of wetpack (economic allocation)

Several studies have shown that emissions connected to the fuel consumption of the fishing vessels is a very important contributor to the environmental impact of the

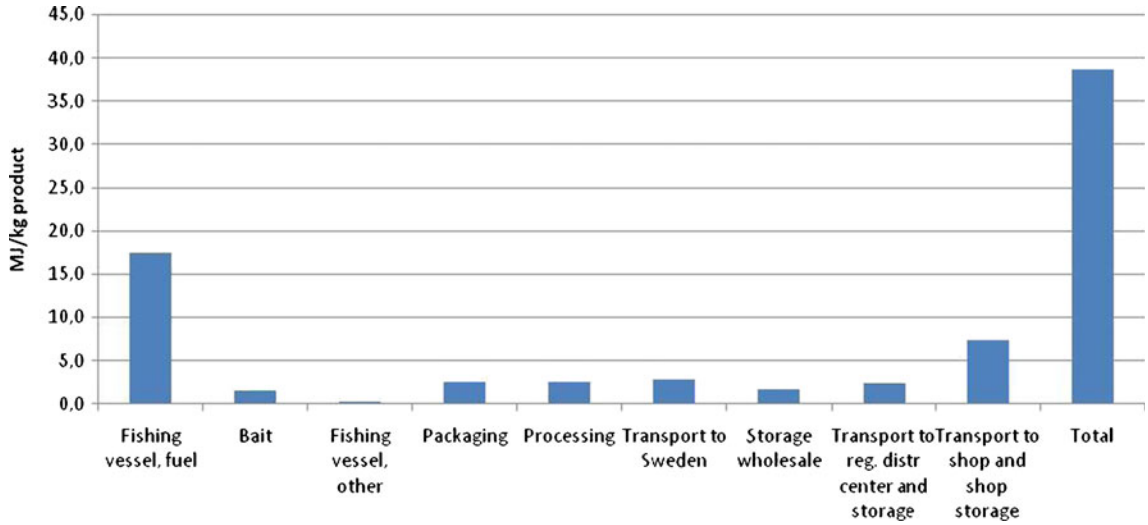

Fig. 5 Distribution of cumulative energy demand across the value chain for wetpack (mass allocation)

fisheries. In this study, the fuel consumption was 0.29 l/kg whole caught fish. Schau et al. (2009) reported an average fuel consumption of 0.41 l/kg for Atlantic cod landed in Norway whereas Winther et al. (2009) reported an average of 0.24 l/kg. Studies in other countries have also been done. Thrane (2003, 2006) reported numbers for trawling of groundfish (0.46 l/kg) and gillnetted groundfish (0.24 l/kg) in the North Sea, Eyjólfsdóttir (2003) 0.65 l/kg for trawled cod in Icelandic waters and Ziegler et al. (2003) 1.5 l/kg for trawled cod and 0.41 l/kg for gillnetted cod in the Baltic Sea. Bottom trawling is another widely used technique for demersal fish species. Winther et al. reported 0.43 l/kg whereas Ellingsen and Lønseth (2005) reported 0.53 l/kg.

6.3 Result of improvement analyses

The LCA results were used to identify hotspots and calculate effect of possible reduction measures. Fuel consumption was, as expected, identified as the largest contributor to environmental load of the products. However, leakage of coolant in the onboard freezer system was also shown to be a very important contributor to environmental impact, mainly GWP. Figure 7 shows the effect of

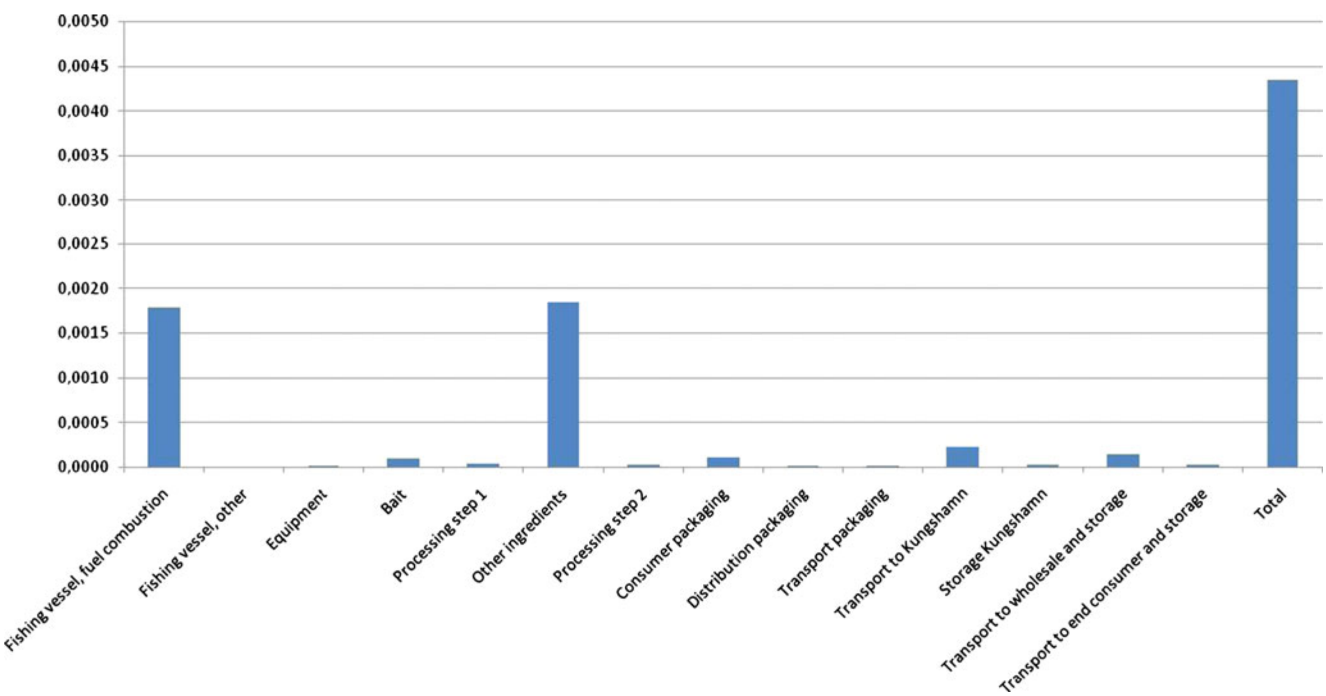

Fig. 6 Distribution of eutrophication impact across the value chain for fish burger (mass allocation)

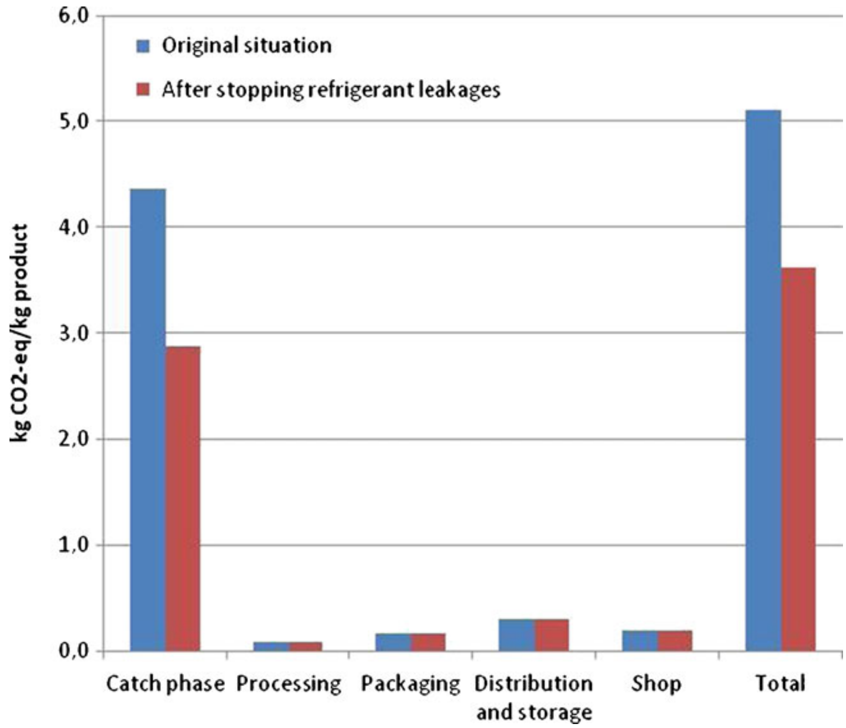

Fig. 7 Improvement in environmental performance achieved by changing refrigerant and stopping leakages in ships freezers

reducing leakages to an industry average (Thrane 2003). The reduction of the refrigerant leakage to the average of the Danish fishing fleet (equivalent of 0.03 g R22/kg landed fish) would give a reduction of 29% of the GWP for wetpack.

A reduction of fuel consumption would have a large impact on environmental impact of the products. A sensitivity analyses showed that a 5% reduction would have given a 3.6% reduction of GWP of wetpack. According to the fishing vessel operator, the highest potential for a decrease in fuel consumption would be to fish in areas closer to where the ships are stationed. Sometimes the vessels have to venture far away, typically in the area of Bear Island. The reason for this is that this is where the highest concentration of fish is at that moment. The fuel consumption is also connected to the awarding of maximum allowable quotas for the different fish species. It was, in this project, not possible to find any short-term measures that could have given a quantifiable reduction in fuel consumption. It is possible to reduce the environmental impact connected with the bait by using waste materials from fish processing. Such bait has been developed for haddock, but not for cod. Such bait could reduce the GWP of the bait by 84% and the primary energy consumption by 76%, calculated per kilogram bait. The reduction in GWP of the finished product depends on the amount of bait necessary for each kilogram fish caught and on selectivity effects. Given that the same amount of bait is used per kilogram of fish caught and the species selectivity would be unchanged, a potential reduction of 3% of total GWP of the finished seafood products was calculated. Other potential environmental improvement measures were explored. One possibility is to utilise the raw material in a more efficient way, i.e. increase the output for human consumption. About 40% of the gutted fish is used as animal feed. Not all of this is skin and bones. The "earcut" fraction is the fraction of the fish first removed in the processing. It consists of parts of the backbone of the fish, but some fish tissue suitable for human consumption is also included in this fraction. If this part of the earcut had been used for human consumption, it would have a much higher economic value. The effect is only noticeable if economic allocation is used. The effect would be a reduction of environmental impact; for GWP of wetpack, a reduction of 1%. Another effect of such a measure is to increase the yield for human consumption and decrease the pressure on natural resources, an effect not measured in this project. The processing company had targets for reducing the energy demand, packaging wastage and water consumption. The reduced energy consumption had the largest effect on the total impact of the products. A 17% reduction in energy consumption would reduce GWP of wetpack by 0.3%.

Loins are transported in EPS boxes using ice to keep the product chilled from manufacture to delivery to reprocessing plant. Packaging made from laminated cardboard is a potential alternative to EPS boxes for this application. The effect of such a substitution could be a reduction of 0.7/1.1% of total GWP of the loins product using economic/mass allocation. The use of ice could be eliminated by employing a controlled thawing step that would raise the

temperature to only 1–2°C, instead of the typical 5°C before processing. Elimination of ice would necessitate a very tight control of the temperature during distribution, e.g. trough using time–temperature indicators outside the boxes. If ice could be eliminated and the boxes filled up with loins instead, a theoretical reduction in total GWP for the loin product of 0.9/1.4% (economic/mass allocation) could be achieved.

7 Discussion

Information on the environmental sustainability of seafood products is available on many products on the marketplace today, mostly in the form of ecolabels such as MSC, Friend of the Seas and KRAV. However, as pointed out by Thrane et al. (2009), most labels do not address all relevant environmental aspects and they mostly concern only the fishing stage. The impact of global warming is one such impact seldom addressed. Several of the products in this study have been awarded certification for the ecolabels KRAV and MSC. An important motivation for the processing company participating in this project was to provide private consumers, business customers and other interested parties with information on impacts such as GWP connected with the industrial processes throughout the value chain needed to bring the studied seafood products to the market. However, in our experience, the involved companies had difficulties in comprehending the results unless compared with other products. Generic comparisons made by Ellingsen and Aanondsen (2006) and Winther et al. (2009) indicate that some seafood products has lower GWP than some meat products. Several studies, such as Winther et al. (2009) show that some fish species give rise to lower impacts than others, e.g. pelagic fish such as herring and mackerel having lower impact than carnivorous species such as cod. Such results could be a guide to customers who want to reduce their environmental impact but there seem to be little information available to help consumers choose between seafood products from the same species. A literature study was made in order to enable a comparison of the results of this study with results from other studies and thus make the results more comprehensible to customers and other possible users of the data. This comparison indicates that the environmental performance of products derived from autoline-caught cod is on par with or slightly better than the average cod products on the markets in Europe. ICES (2005) and Gjøsæter et al. (2010) have shown that the biological status of the cod stocks in the Atlantic Ocean is very different from stock-to-stock. Some are sustainably managed, others not. Ideally, such information on the “biological” sustainability of the fish raw material should be coupled with information with the information on the “industrial” sustainability which has been the subject of this study. Hence, the results of this study should ideally have been compared to information on products sourced from the same cod stock, the Northeast Arctic cod. However, no sure conclusions can be made before other products on the market are studied with the same methodology and applied in the same way as in this study.

7.1 Documentation of environmental performance of studied seafood products

The studied seafood products are the results of a processing where the aim has been diversification of products and optimal utilisation of the raw material. Rather than just removing the fillets and using (or not using) the residue for other purposes the aim has been to differentiate between different parts of the fish having different qualities, in the same way that meat producers do. The seafood products in this study represent a wide variety of applications and hopefully could be useful in other studies. The differences in environmental impact between the products are partly due to differences in methodological choices such as system borders and allocation method, partly to differences in the products fate after processing. The aim was to include the life cycle of the products from fishing to the point of purchase. The value chain after purchase was not included, not because it is irrelevant but because it depends more on the consumer’s individual preferences and habits rather than the properties of the products. Due to lack of data, two of the products could not be followed to the point of purchase. For the loins product, the impact of the transport from the regional distribution centre to retail and the retail phase was not included. For the processing residue, the impact of reprocessing into animal feed and distribution to user was not included. Based on the numbers for processing and transport of the other products, it can be assumed that the impacts of these omissions are relatively low in comparison with the total impact. The most important reasons for the high impact of the loins product is that it is processed and packaged twice, transported over very large distances and transported with a low utilisation of load capacity from port to processing centre in the UK. This extra transport and processing is expensive both in terms of resource use and economical terms but is justified by the fact that this product is highly valued by consumers.

The wetpack product was a very simple product that is packaged raw, frozen and transported a relatively short distance, hence it had a lower impact than the loins product. The fish burgers had an even lower impact even though it has gone through two processing stages. The reason for the low impact is that it consists partly of raw materials of plant origin which has a lower environmental impact than the

cod. The processing residue has the lowest impact, partly due to the limited system border, but also due to short transport distances and efficient transport. This residue was in the past discarded as waste.

7.2 Importance of methodological choices

This study has showed that choice of allocation method was very important for the results. The large differences in the results when using mass allocation and economic allocation can be explained by large differences in prices. Cod is an expensive fish species compared to the other fish species caught. This means that the ratio of the economic value of the cod to the entire catch economic value is higher than the ratio of the catch weight of cod to the entire catch weight. The price differences between the processing outputs are very high. The price of the loins is nearly 100 times higher than the price of the processing residue. This explains the large difference in results of these products when using economic allocation compared to mass allocation. Svanes et al. (2011) has studied some of the possible impacts of using mass or economic allocation in different applications, in particular in external communication to customers and internal improvement work. Using mass allocation, the utilisation of fish guts will seem a very important reduction measure no matter how high the price this residue fetches. Using economic allocation, the potential reduction depends on the price. If the price is low, the environmental impact will be low. Using economic allocation, it would be environmentally beneficial to increase the output of products with a high economical value, using mass allocation there would be no effect if the yield of products for human consumption goes up of down, as long as the total yield for human and animal consumption is not changed. Another application is communication to customers. Using economic allocation, customers might conclude that it is environmentally better to avoid the loins product and wetpack, choosing the fish burgers instead. If mass allocation had been applied, the customers would have little environmental incentive to choose fish burgers over wetpack, whereas the incentive not to buy the loins product would remain but be far less than when using economic allocation. Using mass allocation, the processing residue will have a much higher impact than when using economic allocation. Thus, the animal feed producer chooses other raw materials than fish processing residue, materials with a higher feed value/environmental impact ratio. This might lead to a lower utilisation of processing residue. No internationally accepted calculation method for the environmental impacts of seafood products exists. This means that the comparability of the results from this study with results from studies of other products on the market will probably be low, unless the same methodology has been used. The ILCD Handbook can be a very useful input to the development of a standard. Magerholm Fet et al. (2009) has provided a framework that also can provide useful input. However, these studies and guidelines do not provide the accurate guidance necessary to ensure comparability of data needed in, e.g. purchasing decisions.

7.3 Improvement analyses

The most important improvement option identified on the medium and short term was to significantly reduce the emissions of refrigerant in freezers onboard fishing vessels. Fishing vessels are highly exposed to salt and moisture. This creates a corrosive environment. The equipment onboard is designed to withstand corrosion; but over time, it is very difficult to totally eliminate refrigerant leakages. Thus, a transition to refrigerants that have a low environmental impact was also viewed as an important measure to reduce the refrigerant problem. Newly repaired refrigeration unit would probably not leak at all. In this case, the average impact of leaked refrigerant in the Danish fleet has been used to describe the post-repair situation. Hence, it is likely that the actual reduction of the GWP would be higher than the calculated numbers indicate. The environmental benefit of using bait made from waste materials was demonstrated. Another possible effect of new bait is increased selectivity towards one or several species. Already selective haddock bait exists. Selective cod bait could potentially reduce unwanted bycatch and thus reduce pressure on fish stocks. Reduced fishing effort and hence reduced fuel consumption is also possible because the quota would be filled in a shorter time period. The effect on the studied LCA impact categories of such bait is difficult to calculate because there are too many uncertainties involved. Such high selectivity can be important in many of the world fisheries where unwanted bycatch, and thus discard is high. The importance is probably less in this autoline fishery where all bycatch is utilised. The investigated improvement options in the processing plant were shown to have a limited impact on the overall environmental performance of the products. The impact of better utilisation of the earcut fraction is small but still important when considering the volumes being processed. The effect of new processing and transport solutions are also far less than the effect of stopping leakages of coolant onboard. However, a reduction of a mere 1% in GWP can be considerable when the production volume is high. It is also important that these solutions also carry economic benefits they are very interesting for the producer. The high impact of the refrigerant leakage was a surprise to all involved actors. Before the project started, the involved companies had regarded reduction of energy use in processing, increased utilisation of earcut fraction and new selective bait as the most important improvement

options. This assessment showed that these improvement options were not the most important options. This shows that the use of LCA enabled the involved companies to identify the most important improvement options rather than investing in improvements giving only a minor benefit and not discovering options that could give a large benefit. Hence, LCA could be said to be an important tool for the environmental improvement work for the fishing company.

8 Conclusions

In this study, the environmental performance of products sourced from Northeast Arctic cod fished by automatic longlining ("autoline") equipment was documented, and a comparison with published results from other studies attempted. Furthermore, the study identified several improvement options, some of which were carried out in real life. The study also showed the importance of methodological choices, especially allocation, on end results. The fishing phase was found to be the life cycle stage giving the most important impacts. An exception was found for the product fish burger, where the production of the other, plant-derived ingredients gave the highest contribution to the eutrophication impacts. For most impacts, the primary source of environmental impact was found to be fuel consumption and for GWP leakage of refrigerants was also important. The improvement analyses identified stopping of refrigerant leakage to be the most important option for improving the environmental performance of the products. Other improvement measures were identified such as improving yield for human consumption in processing, reducing energy consumption in processing and eliminating ice in the transport of chilled loins. An accurate comparison of the environmental impacts of the studied products with published results for other cod-based seafood products was not possible because the products were different and methodological choices in the analyses were also different. The results do, however, indicate that the environmental performance is better or similar to that of average products from Northeast Arctic cod published in other studies. One important motivation for the processing company involved in this project was to communicate the results to the general public. The intention has been that the market can be used as a tool for environmental improvements if consumers and other seafood buyers choose products that have low environmental impact. It is the hope of the authors and involved companies that the data from this study can contribute to such a development. However, at the moment, there is little publicly available information about the environmental performance of seafood products on the worlds markets, except the information on "biological impacts" given by ecolabels such as MSC. Furthermore, no detailed standardised calculation methods for the impacts of the industrial processes necessary to provide the market with seafood products seem to exist, even though framework for such a method has been suggested by several studies, e.g. Magerholm Fet et al. (2009).

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